

UNIVERSITÀ
DEGLI STUDI
DI PADOVA

WNMA Project

Real-time crowd information using Bluetooth: a full-stack solution

Luca Marchiori

25 March 2024

1. Introduction
2. Technology stack
3. System Architecture
4. Field test
5. Results
6. Additional considerations
7. Conclusions

Project Idea: is it possible to exploit Bluetooth to count how many people are there in a room / building and the occupancy trends?

- Seat availability in libraries (without reservation)
- Workforce management (effective deployment)
- Health-critical monitoring (pandemic)

Assumption: BT is a very diffused technology and nowadays most people have a BT-enabled device (smartphone, smartwatch, etc.) with them. Often it is turned on because of low energy consumption.

The scanner is a device that periodically scans ¹the environment for Bluetooth devices and sends the data to the server.
Implemented in Go, can run both on Raspberry Pi and Arduino².

Features

- Low energy consumptions
- Low cost hardware
- Easy deployment

Thanks to linux's crontab, the scanner can be scheduled to run at specific times, e.g. every 5 minutes.

¹Use the go-bluetooth library and the Bluez DBus API

²Can be compiled for Arduino using TinyGo

The server includes both a backend and a frontend developed in a product-ready fashion.

Backend

- Implemented in Go
- RESTful API
- Data storage: SQLite

Frontend

- Implemented in React
- Real-time data visualization

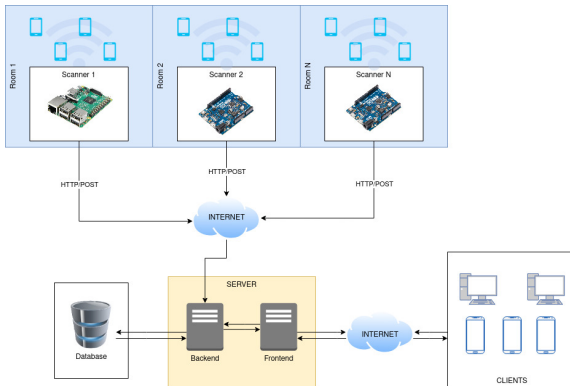


Figure: System architecture

The system has been tested in a real environment: a small local library.

- The scanner (Raspberry Pi) has been placed in a central position
- To avoid hosting costs, the server has been deployed on the Raspberry loopback interface
- Three days of data collection with few people in the library

Field test



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

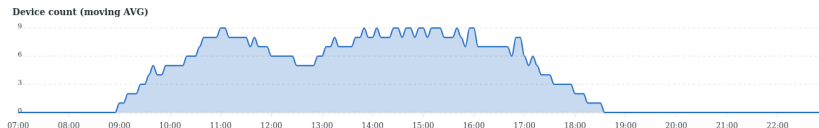


```
[INFO][0001] New device discovered: addr=68:7f:57:01:77:80 rssi=-100 alias=68-7f-57-01-77-80 name=
[INFO][0001] New device discovered: addr=45:81:05:55:10:02 rssi=-95 alias=45-81-D5-55-30-02 name=
[INFO][0001] New device discovered: addr=3C:3C:AE:22:85:E6 rssi=-91 alias=3C-3C-AE-22-85-E6 name=
[INFO][0001] New device discovered: addr=03:A7:04:F0:1E rssi=-92 alias=03-A7-A1-04-F0-1E name=
[INFO][0002] New device discovered: addr=63:03:2E:FB:EA:DE rssi=-87 alias=63-03-2E-FB-EA-DE name=
[INFO][0002] New device discovered: addr=47:C8:15:8C:0A:F3 rssi=-77 alias=47-C8-15-8C-0A-F3 name=
[INFO][0002] New device discovered: addr=40:F0:08:09:20:C3 rssi=-84 alias=40-F0-08-09-20-C3 name=
[INFO][0002] New device discovered: addr=54:84:3E:05:7F:88 rssi=-87 alias=54-84-3E-05-7F-88 name=
[INFO][0002] New device discovered: addr=64:45:09:F8:13:86 rssi=-98 alias=64-65-00-F8-13-86 name=
[INFO][0002] New device discovered: addr=7B:4B:A3:E3:96:17 rssi=-90 alias=7B-4B-A3-E3-96-17 name=
[INFO][0002] New device discovered: addr=59:06:7F:02:29:4E rssi=-102 alias=59-06-7F-02-29-4E name=
[INFO][0002] New device discovered: addr=77:1D:AA:49:25:55 rssi=-93 alias=77-FB-0A-AD-77-55 name=
[INFO][0002] New device discovered: addr=6A:32:99:3E:38:40 rssi=-94 alias=6A-32-99-3E-38-40 name=
[INFO][0002] New device discovered: addr=7C:3C:F8:3E:38:60 rssi=-88 alias=7C-3E-38-60 name=
[INFO][0002] New device discovered: addr=60:57:18:04:76:77 rssi=-94 alias=60-57-18-04-76-77 name=
[INFO][0002] New device discovered: addr=58:70:00:52:58:30 rssi=-94 alias=58-70-00-52-58-30 name=
[INFO][0002] New device discovered: addr=43:10:42:09:04:09 rssi=-91 alias=43-10-42-09-04-09 name=
[INFO][0003] New device discovered: addr=4A:51:86:2D:56:83 rssi=-91 alias=4A-51-86-2D-56-83 name=
[INFO][0003] New device discovered: addr=5A:0F:2D:44:21:88 rssi=-89 alias=5A-0F-2D-44-21-88 name=
[INFO][0003] New device discovered: addr=43:EA:40:F2:8D:01 rssi=-100 alias=43-EA-40-F2-8D-01 name=
[INFO][0003] New device discovered: addr=00:7C:2D:FB:06:05 rssi=-95 alias=00-7C-2D-FB-06-05 name=
[INFO][0003] New device discovered: addr=76:2D:6A:CC:3C:78 rssi=-83 alias=76-2D-6A-CC-3C-78 name=
[INFO][0003] New device discovered: addr=59:61:01:44:88:30 rssi=-87 alias=59-61-01-44-88-30 name=
[INFO][0003] New device discovered: addr=46:50:C7:72:CE rssi=-92 alias=46-50-C7-72-CE name=
[INFO][0004] New device discovered: addr=68:02:5C:AF:04:08 rssi=-97 alias=68-02-5C-AF-04-08 name=
[INFO][0004] New device discovered: addr=7C:91:DE:CC:EC:E6 rssi=-80 alias=7C-91-DE-CC-EC-E6 name=
[INFO][0004] New device discovered: addr=46:43:08:08:07:C5 rssi=-78 alias=46-43-08-08-07-C5 name=
[INFO][0004] New device discovered: addr=7B:45:7A:8E:D2:22 rssi=-98 alias=7B-45-7A-8E-D2-22 name=
[INFO][0004] New device discovered: addr=58:3E:30:C3:C7:F1 rssi=-94 alias=58-3E-30-C3-C7-F1 name=
[INFO][0004] New device discovered: addr=40:03:4D:EE:C5:A0 rssi=-93 alias=40-03-4D-EE-C5-A0 name=
[INFO][0004] New device discovered: addr=55:05:04:31:59:98 rssi=-101 alias=55-05-04-31-59-98 name=
[INFO][0004] New device discovered: addr=4C:3C:30:30:30:30 rssi=-89 alias=4C-3C-30-30-30-30 name=
[INFO][0005] New device discovered: addr=45:F9:8A:C3:54:61 rssi=-97 alias=45-F9-8A-C3-54-61 name=
[INFO][0005] New device discovered: addr=03:41:59:76:11:C5 rssi=-92 alias=03-41-59-76-11-C5 name=
[INFO][0006] New device discovered: addr=50:16:84:AE:06:23 rssi=-88 alias=50-16-84-AE-06-23 name=
[INFO][0006] New device discovered: addr=89:52:16:AC:26:32 rssi=-89 alias=LAPTOP-1E79595A name=LAPTOP-1E79595A
[INFO][0007] New device discovered: addr=46:F9:09:09:09:04 rssi=-86 alias=46-F9-09-09-09-04 name=
[INFO][0007] New device discovered: addr=61:84:10:BE:FE:7A rssi=-97 alias=61-84-10-BE-FE-7A name=
[INFO][0007] New device discovered: addr=70:AB:36:03:1E:28 rssi=-87 alias=70-AB-36-03-1E-28 name=
[INFO][0007] New device discovered: addr=05:FF:32:15:04:16 rssi=-89 alias=05-FF-32-15-04-16 name=
[INFO][0008] New device discovered: addr=05:C4:28:E2:53:75 rssi=-80 alias=05-C4-28-E2-53-75 name=
[INFO][0008] New device discovered: addr=40:8C:0F:CE:24:0F rssi=-94 alias=40-8C-0F-CE-24-0F name=
[INFO][0008] New device discovered: addr=5E:7F:0D:F0:C4:0C rssi=-99 alias=5E-7F-0D-F0-C4-0C name=
[INFO][0009] New device discovered: addr=7A:7F:55:24:03:78 rssi=-80 alias=7A-7F-55-24-03-78 name=
[INFO][0009] New device discovered: addr=78:46:1C:A3:2F:A6 rssi=-92 alias=78-46-1C-A3-2F-A6 name=
[INFO][0009] New device discovered: addr=47:51:88:66:C6:57 rssi=-95 alias=0241204 name=0241204
[INFO][0009] New device discovered: addr=22:16:F0:01:02:0F rssi=-100 alias=22-14-F0-01-02-0F name=
[INFO][0010] New device discovered: addr=00:06:EB:4B:84:0F rssi=-97 alias=00-06-EB-4B-84-0F name=
[INFO][0010] New device discovered: addr=48:BF:30:5A:2F:39 rssi=-94 alias=48-BF-30-5A-2F-39 name=
[INFO][0010] New device discovered: addr=74:07:03:74:73:40 rssi=-93 alias=74-07-03-74-73-40 name=
```




Simple device count

- High variability in the number of devices detected
- occupancy trend is hard to detect
- Chart is day-based



Moving average device count

- Moving average with window of 25 minutes
- Trend is more visible

$$SMA_k = \frac{p_{n-k+1} + p_{n-k+2} + \cdots + p_n}{k} = \frac{1}{k} \sum_{i=n-k+1}^n p_i \quad (1)$$



Average device count per time

```
SELECT scan.scanTime, COUNT(devices.id) AS numDevices FROM scan
LEFT JOIN devices ON scan.id = devices.scanID
WHERE scan.scannerID = ?
AND scan.scanTime BETWEEN ? AND ?
GROUP BY scan.scanTime;
```

Privacy

- It may be possible to track user behaviour
- Data should be anonymized
- MAC randomization by Google and Apple helps

Data analysis: it is possible to further develop the system for advanced analysis of collected data.

- Affluence predictions
- Patterns
- User behaviour

The prototype has been successfully built as a complete product and seems to work as intended.

Problems

- Test data is insufficient: few days with small amount of people
- Not everyone has BT active
- People may have multiple BT devices
- Results may vary by locations (universities vs post office)

Conclusions

Further test and better data analysis are needed to evaluate the system's effectiveness.

Thank you for your attention!